Performance and Safety Tests of Lithium-ion Cells Arranged in a Matrix Design Configuration

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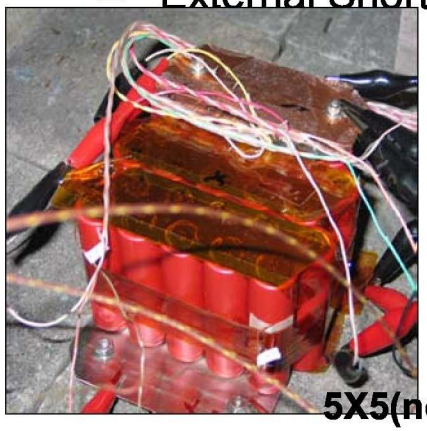
The 2010 Space Power Workshop
April 20-22, 2010

Introduction

- Commercial lithium-ion batteries in portable electronic equipment have been used by NASA for space applications since 1999.
- Latest Lenovo Thinkpad Battery has cells in a matrix configuration.
- Used Quallion matrix packs to understand the performance as well as safety
- Test Articles:
  - Two 5X5 Matrix Packs (One with Heat Absorbent Material (HAM) and one without)
  - One 8X8 Matrix Pack (without HAM)

  Cells are from Sanyo (cobaltate in the 8X8 and spinels in the 5X5)
- Tests:
  - Short term cycle life: 100 cycles (all three packs)
  - Additional 100 cycles with one cell removed (5X5 packs only)
  - Overcharge Test : 5X5 packs
  - External Short: 8X8 pack

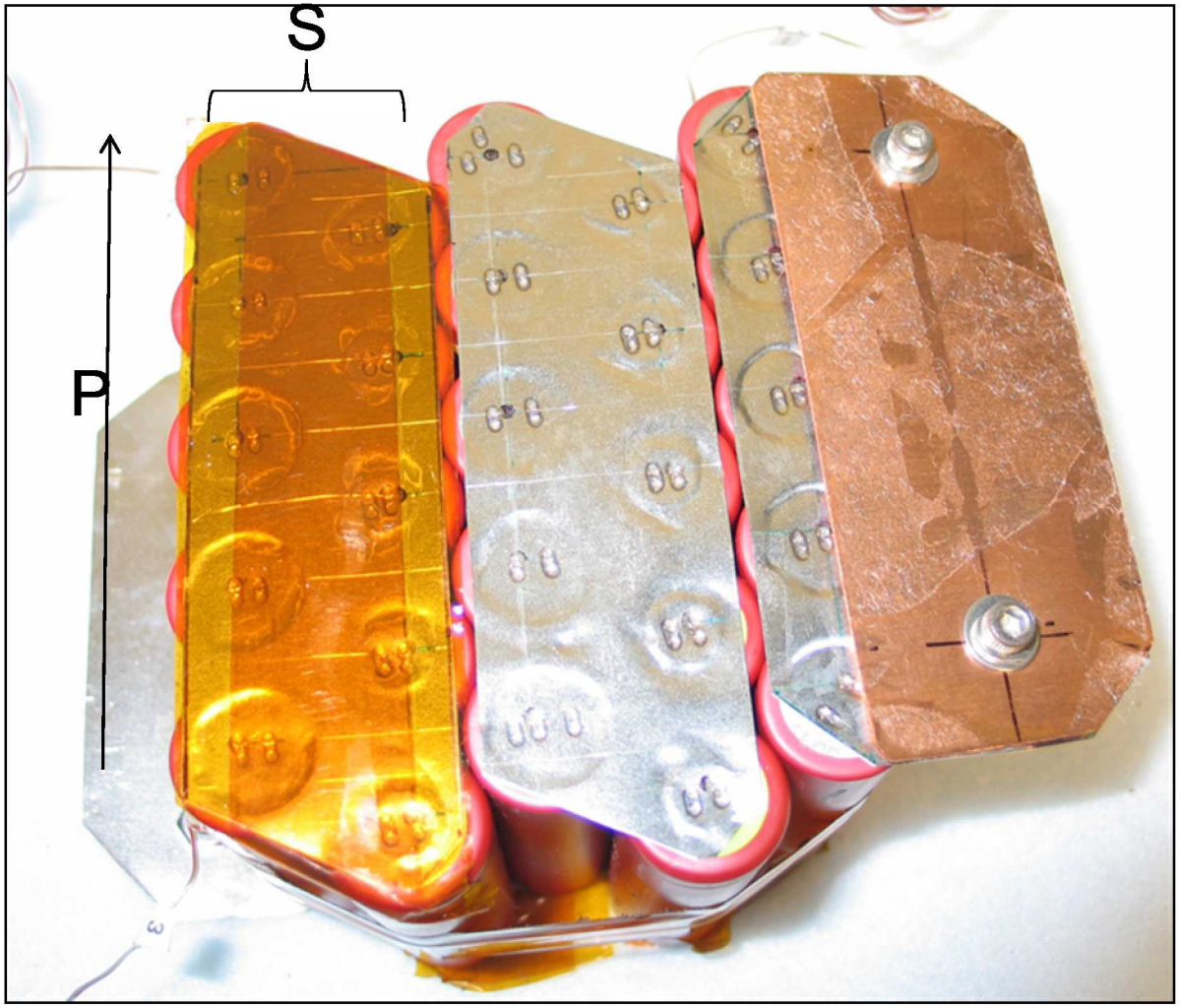


5X5(no HAM)

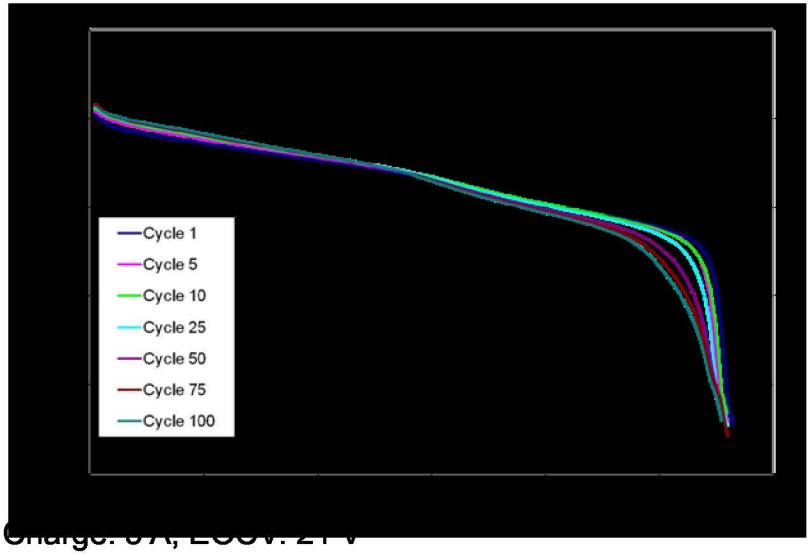
5X5(with HAM)

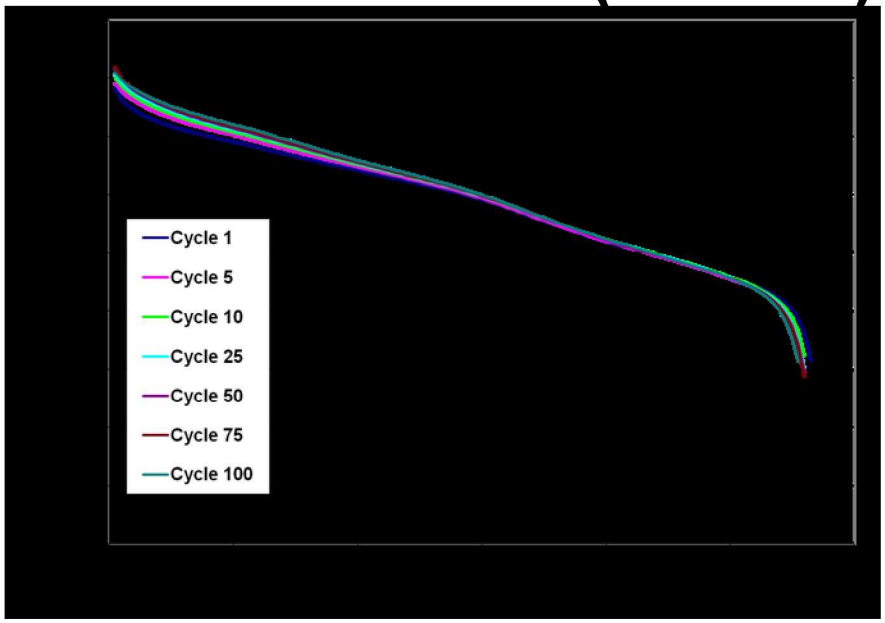
8X8

Matrix Pack Configuration



Cycle Life Test for 5X5 Lithium-ion Matrix Pack (no HAM)

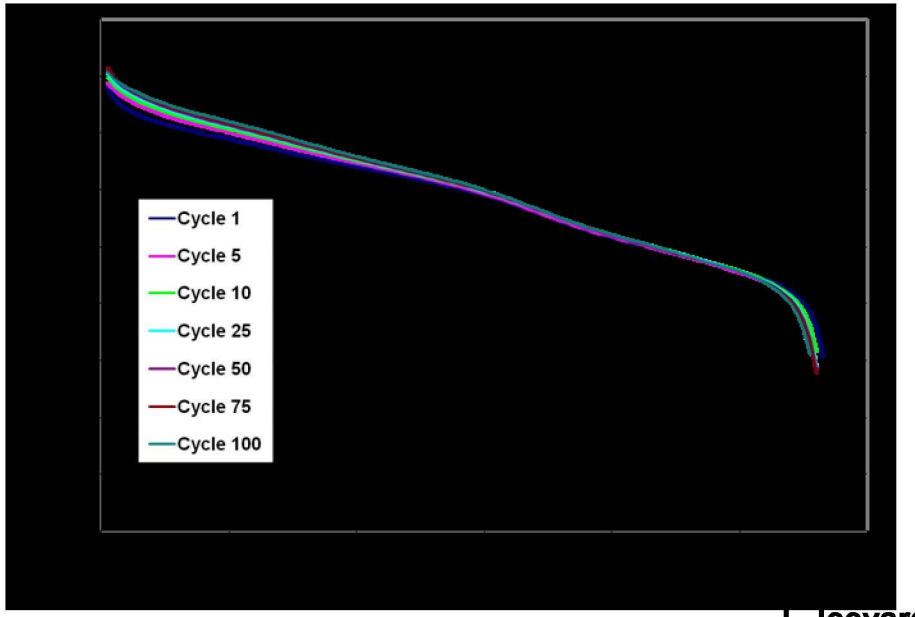


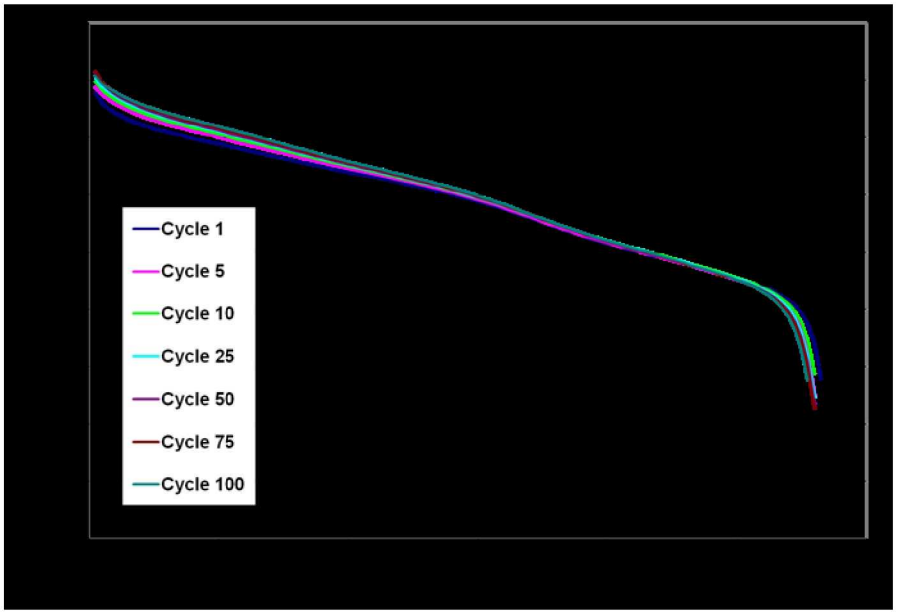


Charge: 5A; EODV: 21 V

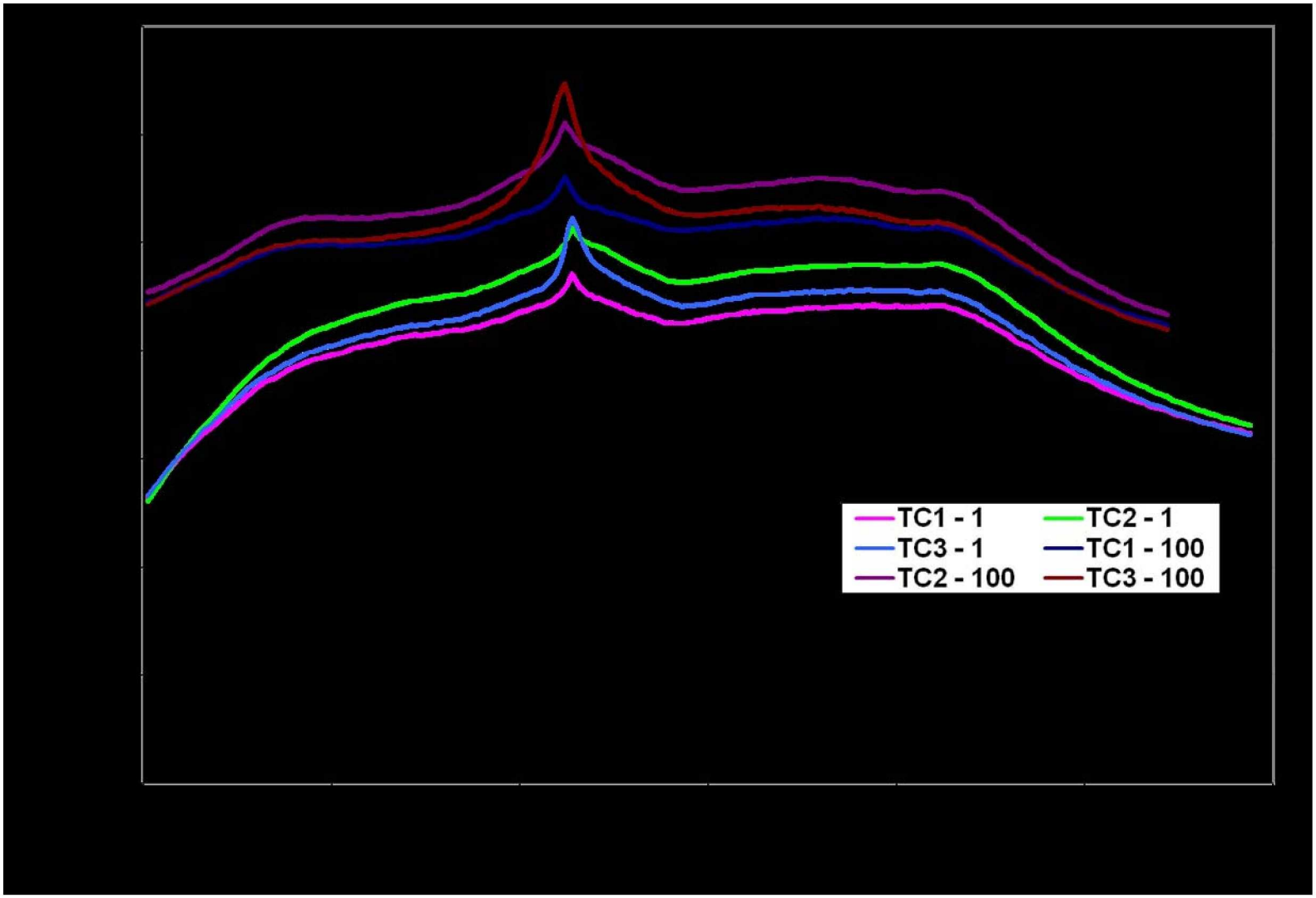
Discharge: 5A; EODV: 13.5 V

Plots indicate bank to bank variation

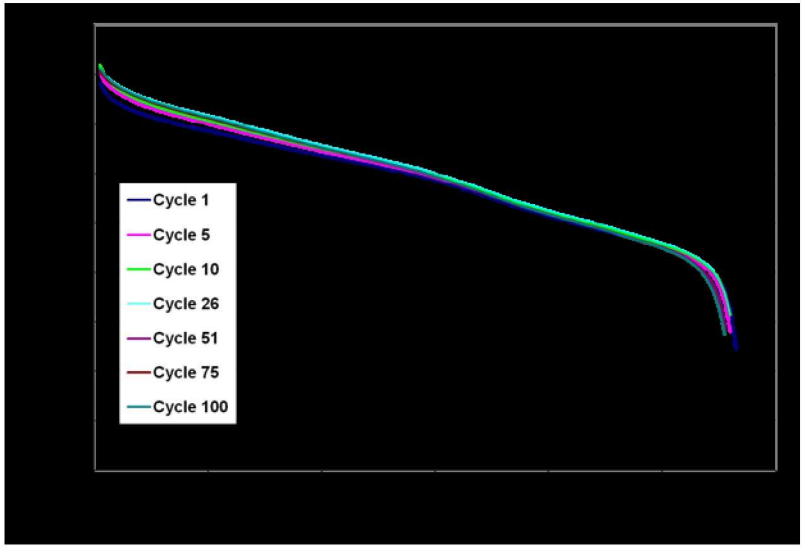


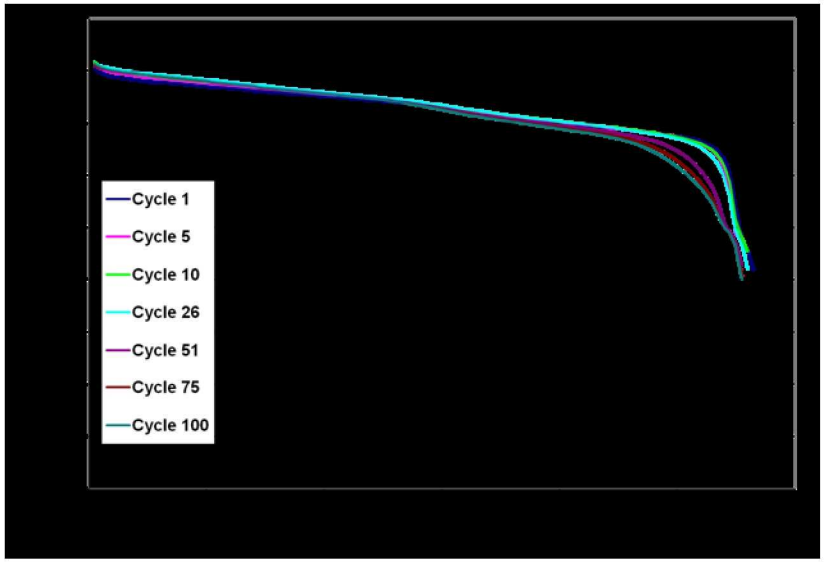


Thermal Profile Trend for 5X5 Lithium-ion Matrix Pack (no HAM)



Cycle Life Test for 5X5 Lithium-ion Matrix Pack (with HAM)





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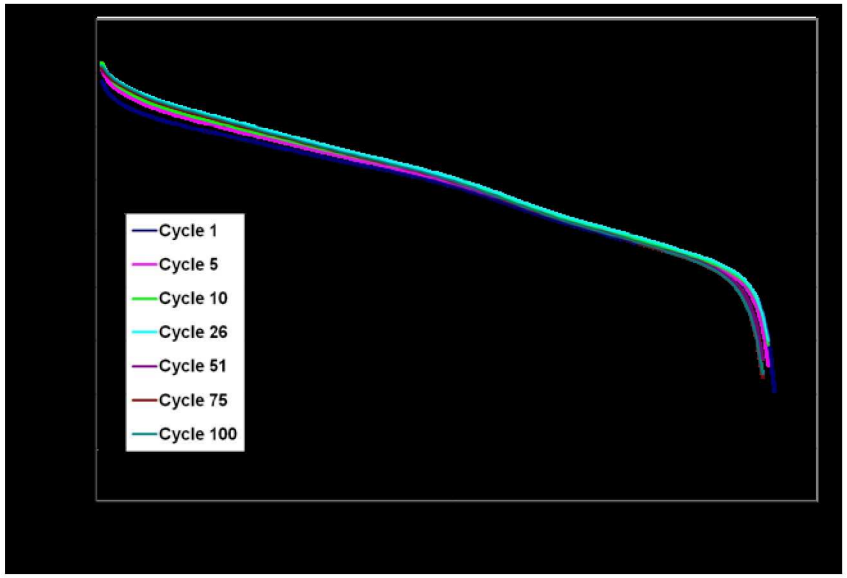
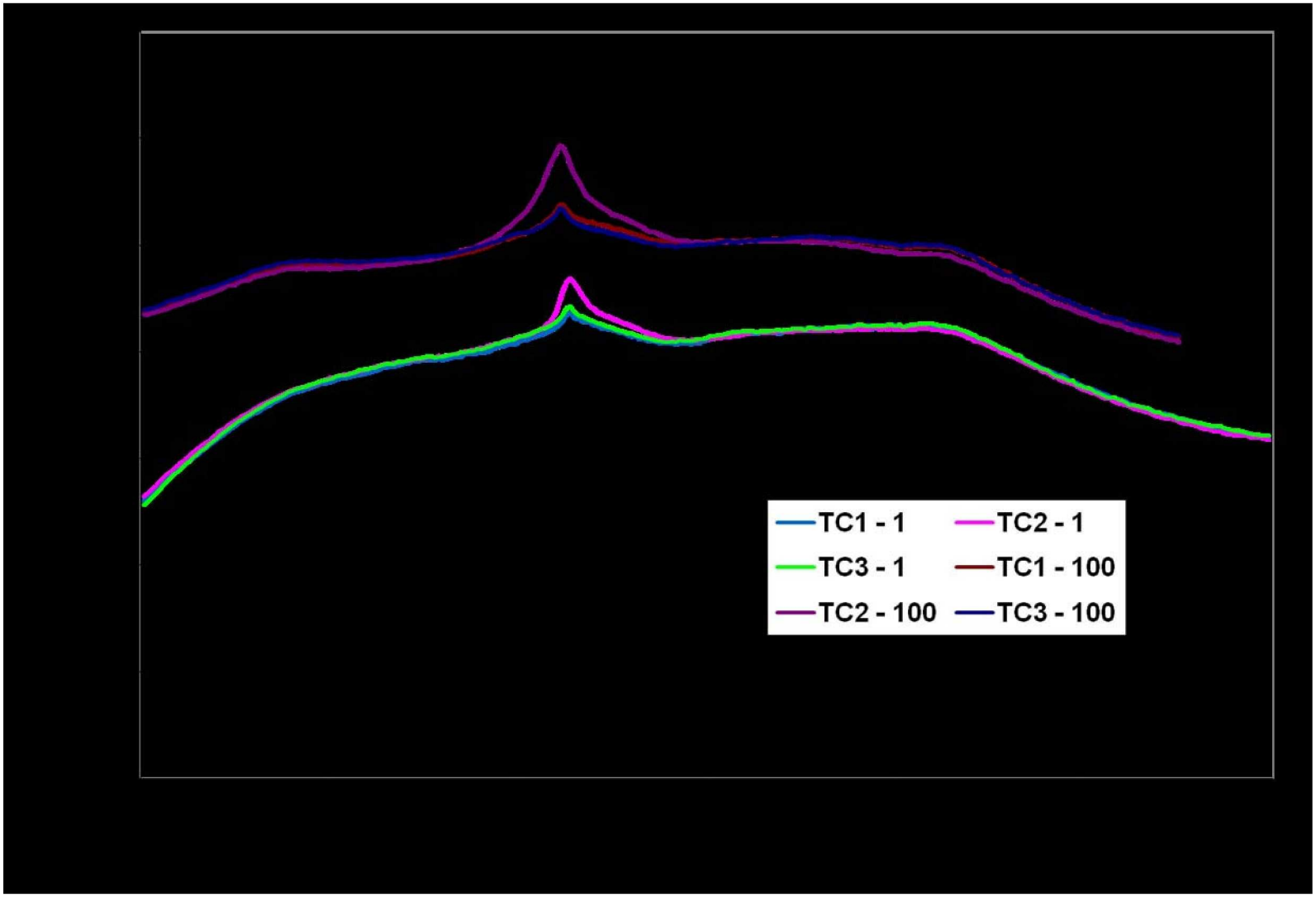
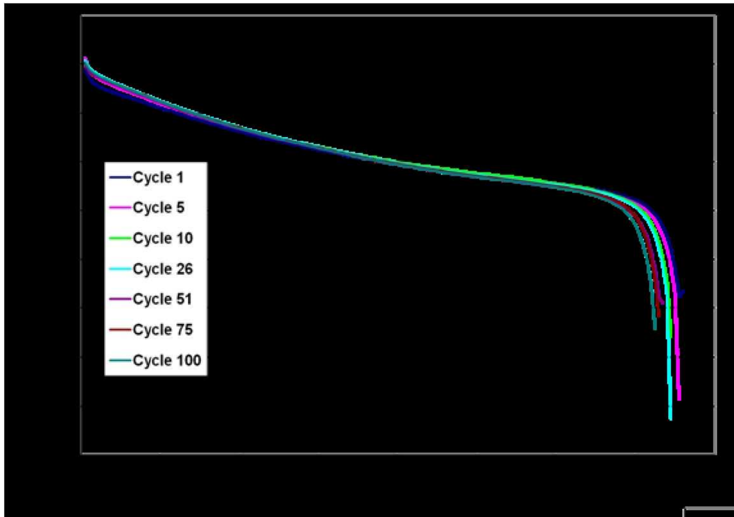
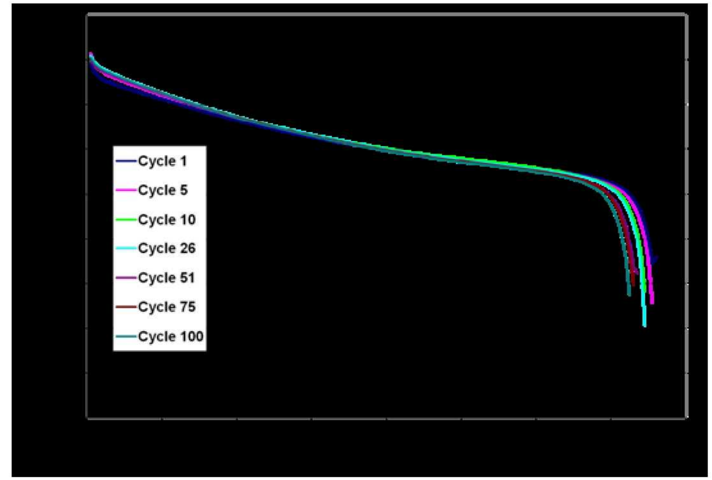


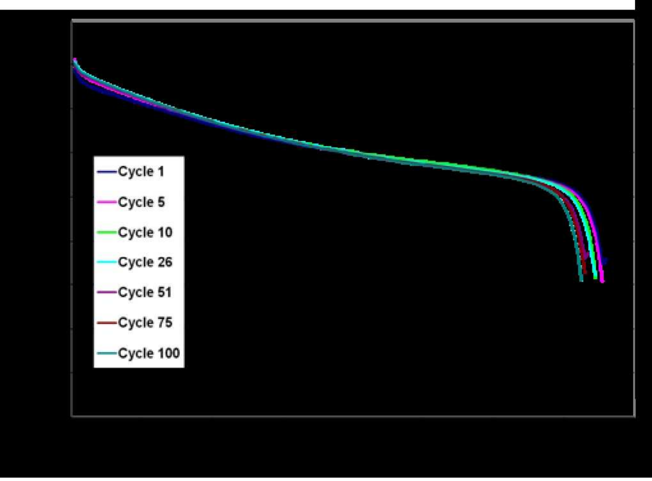
Thermal Profile Trend for 5X5 Lithium-ion Matrix Pack (with HAM)

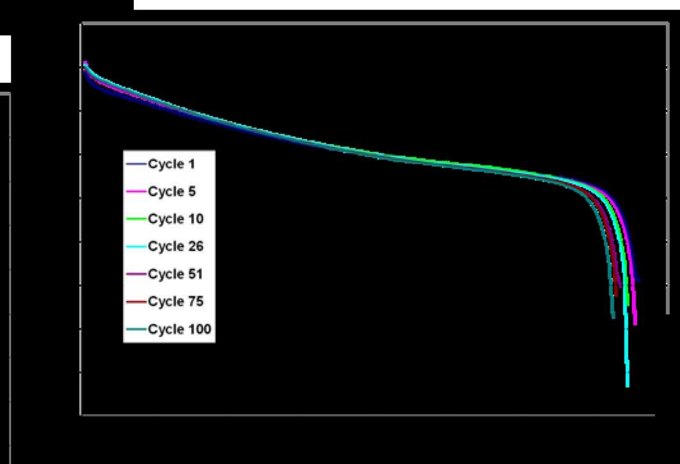


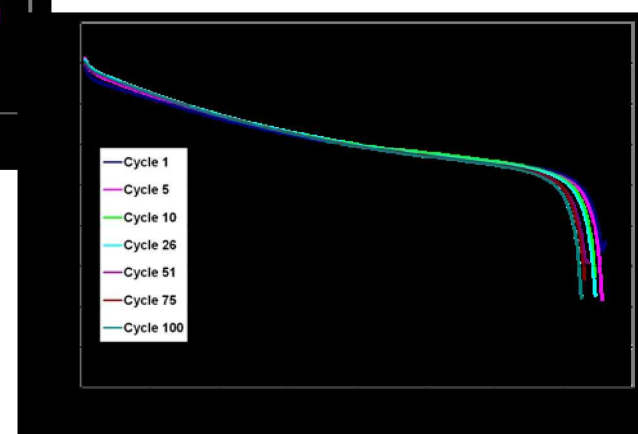
Cycle Life Test for 8X8 Lithium-ion Matrix Pack





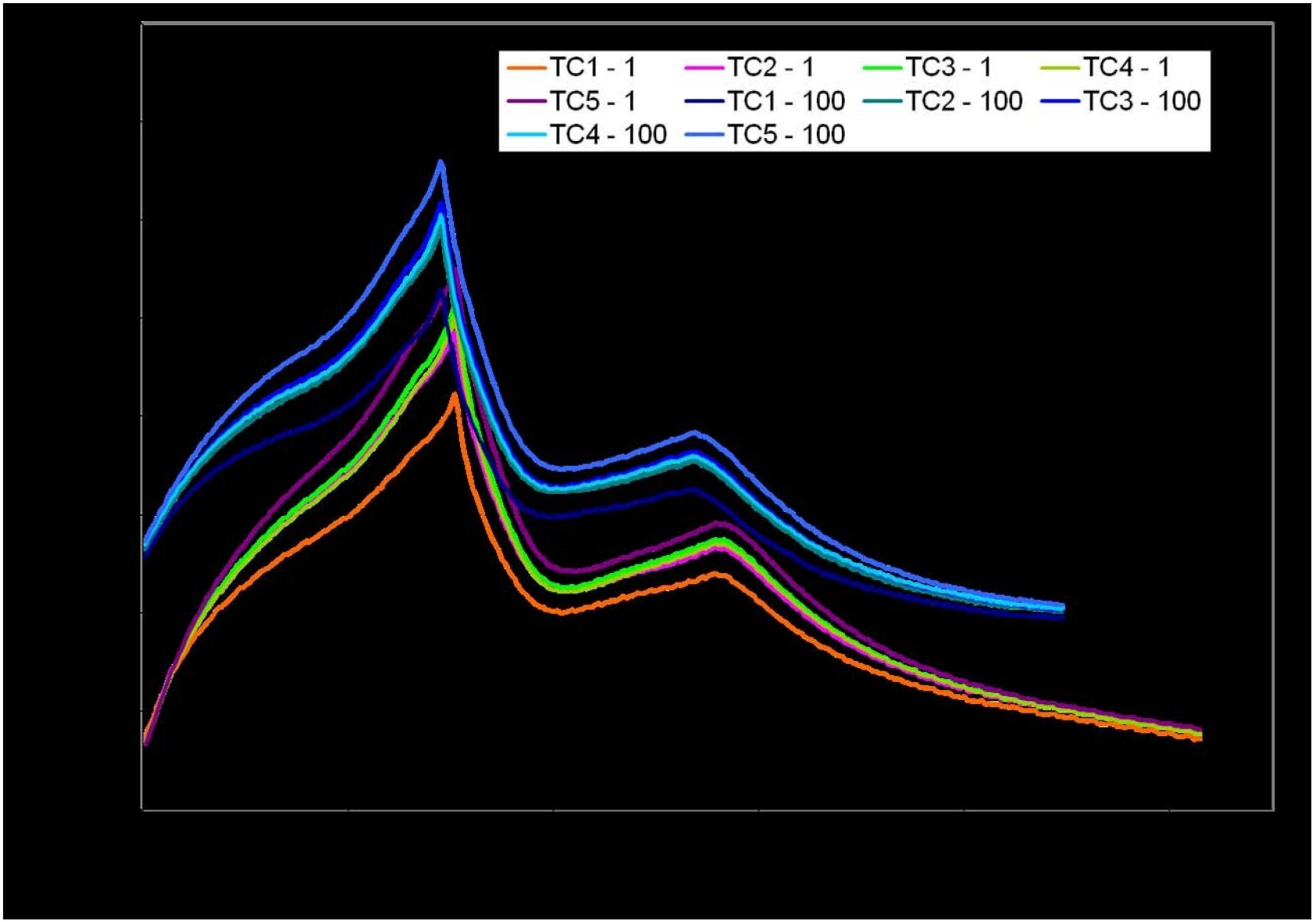






Charge: 8 A; EOCV: 33.6 V
Discharge: 8 A; EODV: 21.6 V

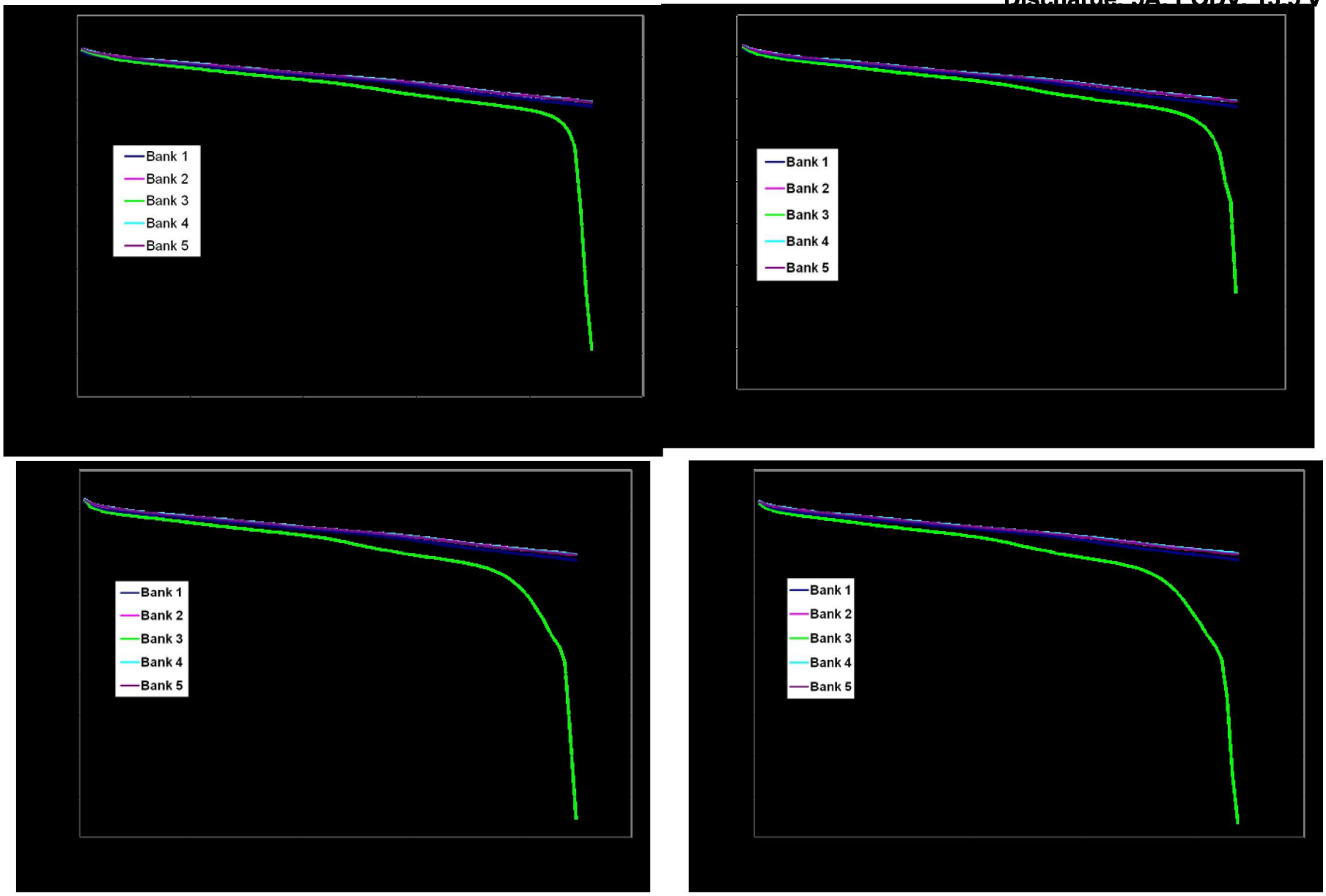
Cycle Life Test for 8X8 Lithium-ion Matrix Pack



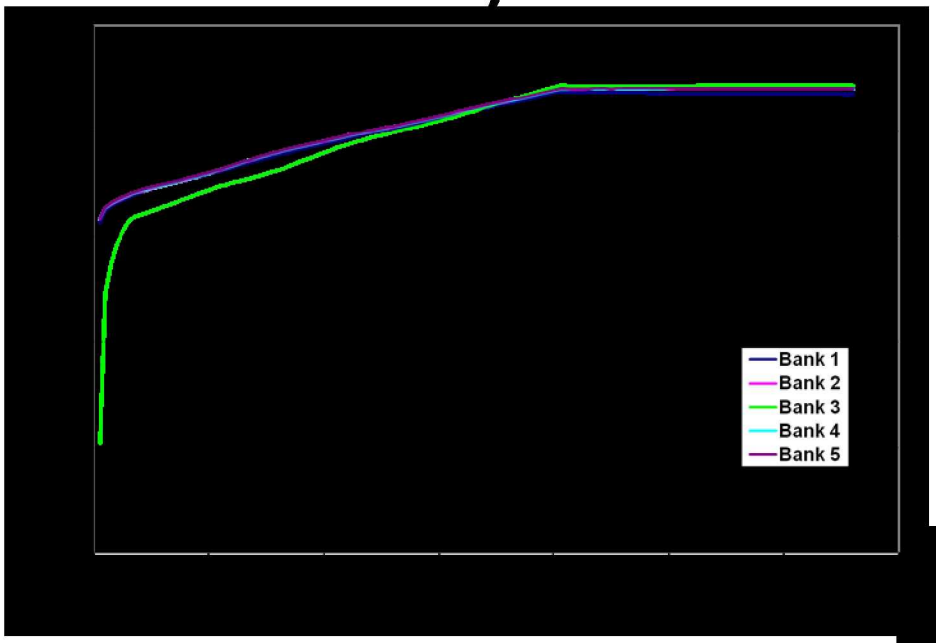
Cell Disconnection from Middle of Cell Bank

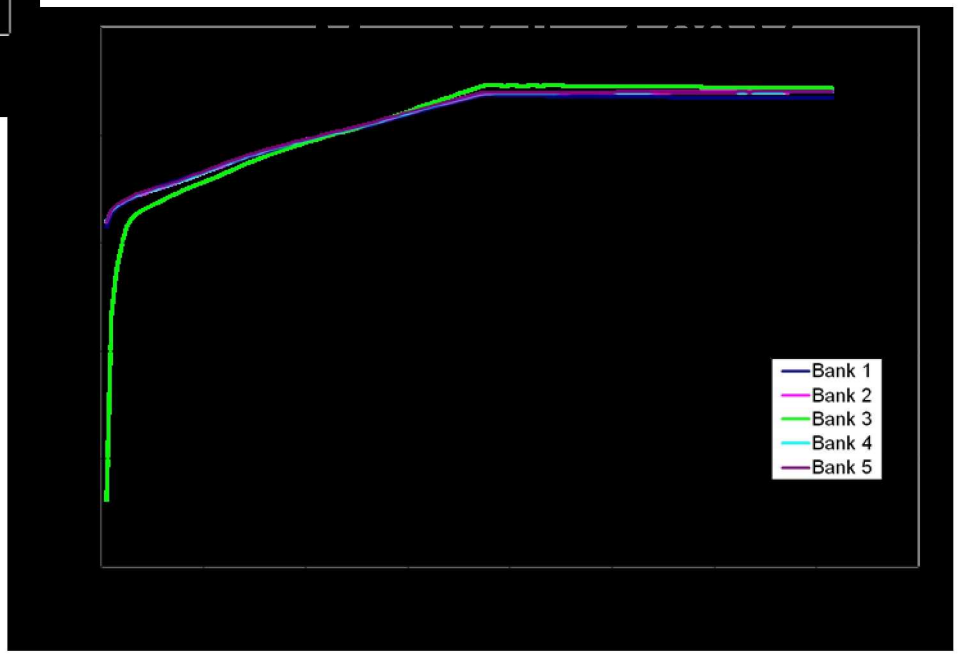
Cycle Life Test for 5X5 Lithium-ion Matrix Pack (no HAM) With One Cell Disconnected

Charge: 5 A; EOCV: 21 V
Discharge: 5A; EODV: 13.5 V



Cycle Life Test for 5X5 Lithium-ion Matrix Pack (no HAM) With One Cell Disconnected

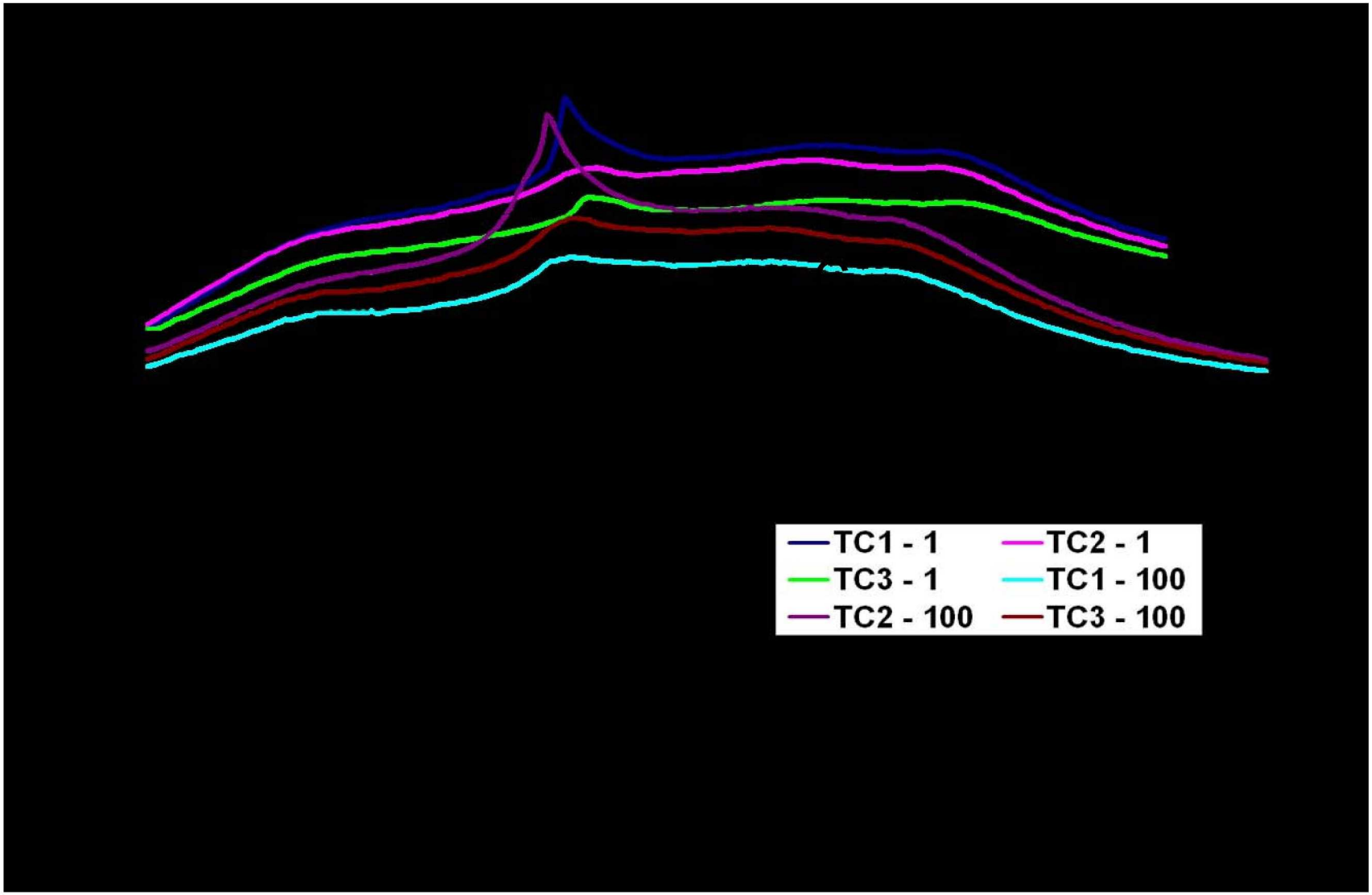




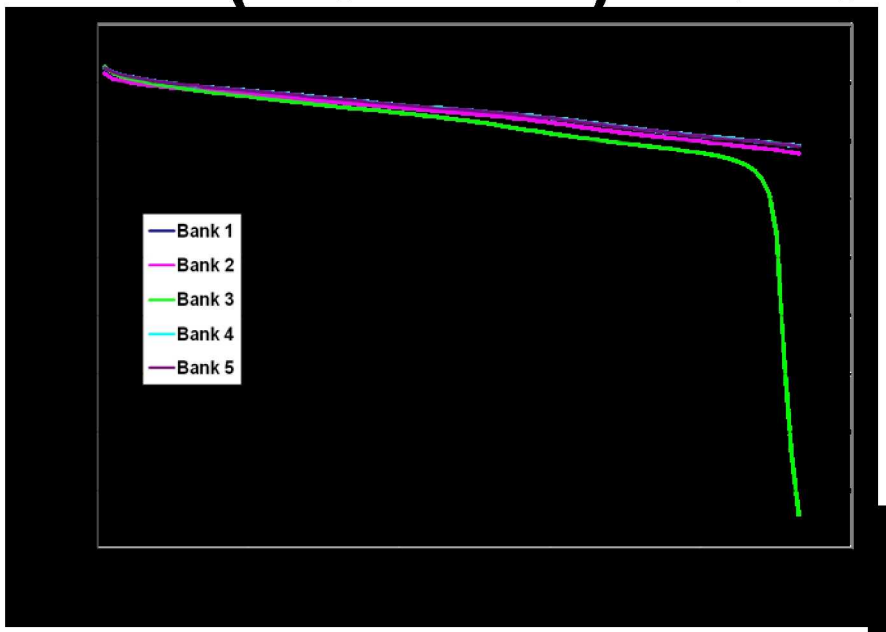
At 2nd Cycle:
Max volt difference: 38 mV
Diff between lower voltage banks is 25 mV

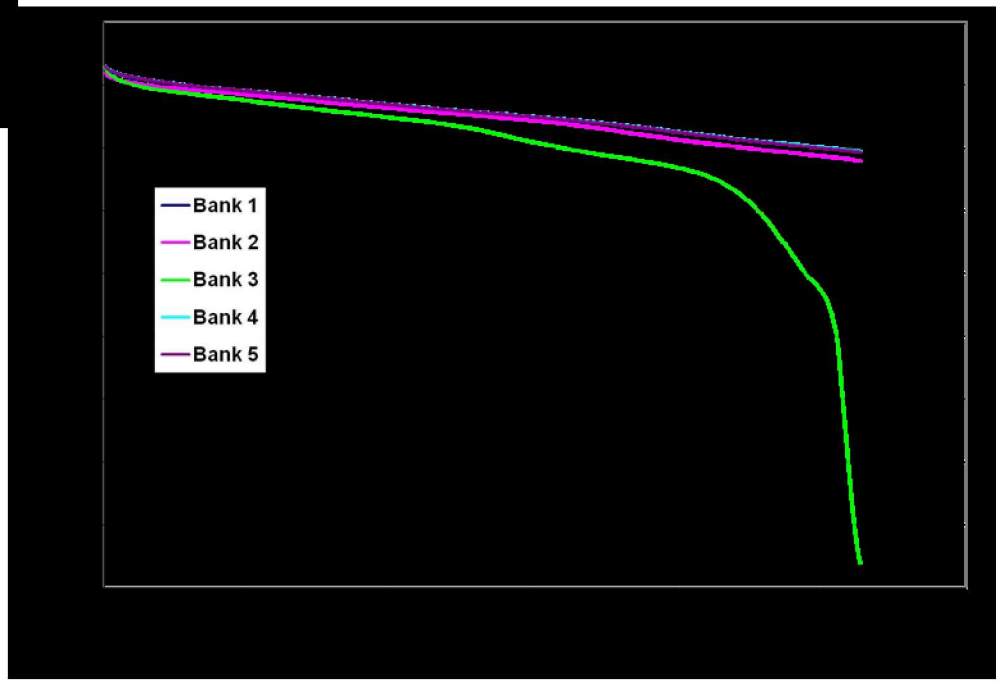
At 100 cycles:
Max volt difference: 55 mV
Diff between lower voltage banks is 25 mV

Temperature Profile for the 1st and 100th Discharge and Charge Cycle for 5X5 Pack (no HAM) With One Cell Disconnected



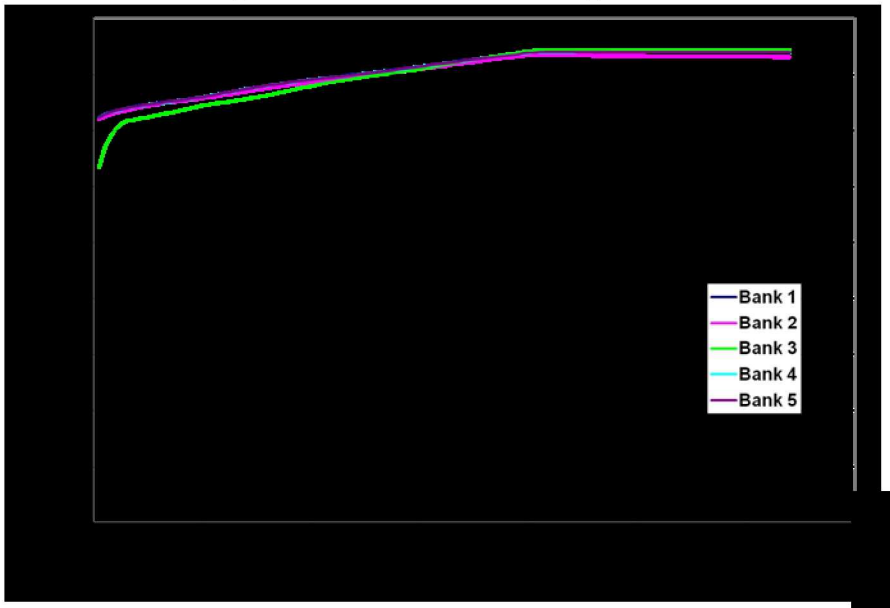
Cycle Life Test for 5X5 Lithium-ion Matrix Pack (with HAM) With One Cell Disconnected



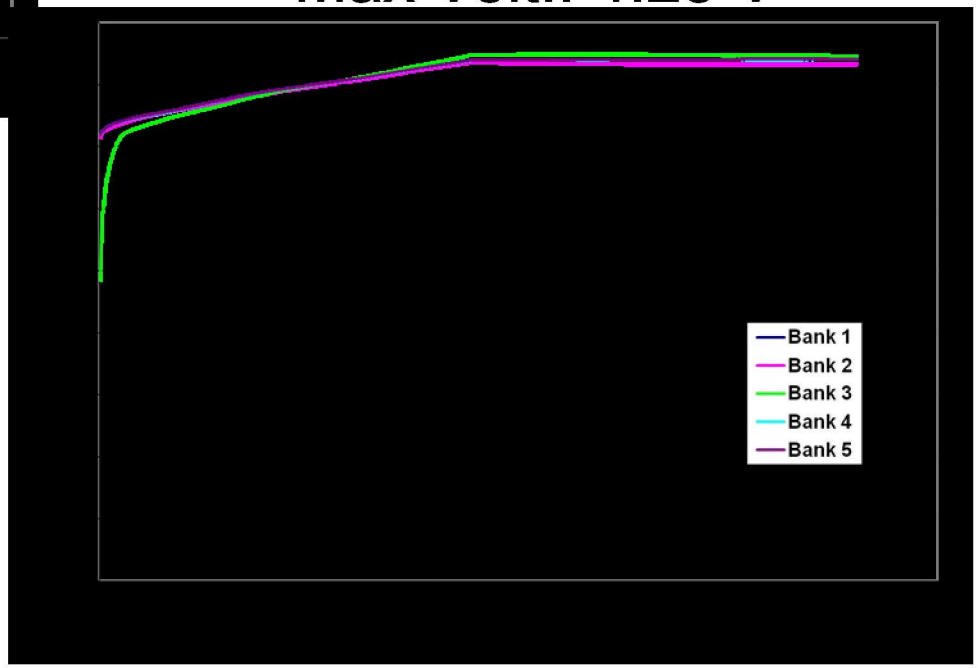


Charge: 5 A; EOCV: 21 V
Discharge: 5A; EODV: 13.5 V

Cycle Life Test for 5X5 Lithium-ion Matrix Pack (with HAM) With One Cell Disconnected



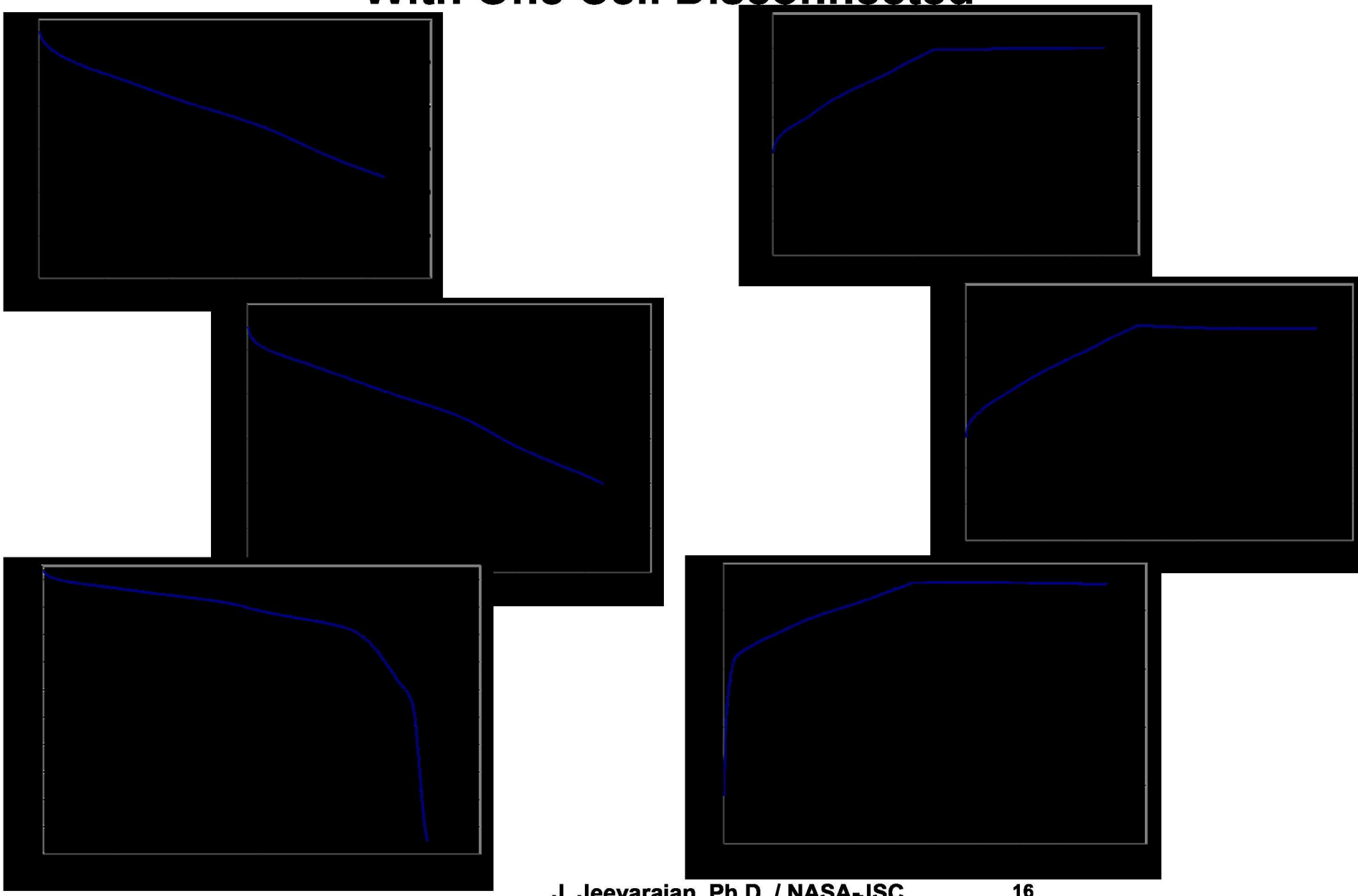
Max Volt.: 4.23 V



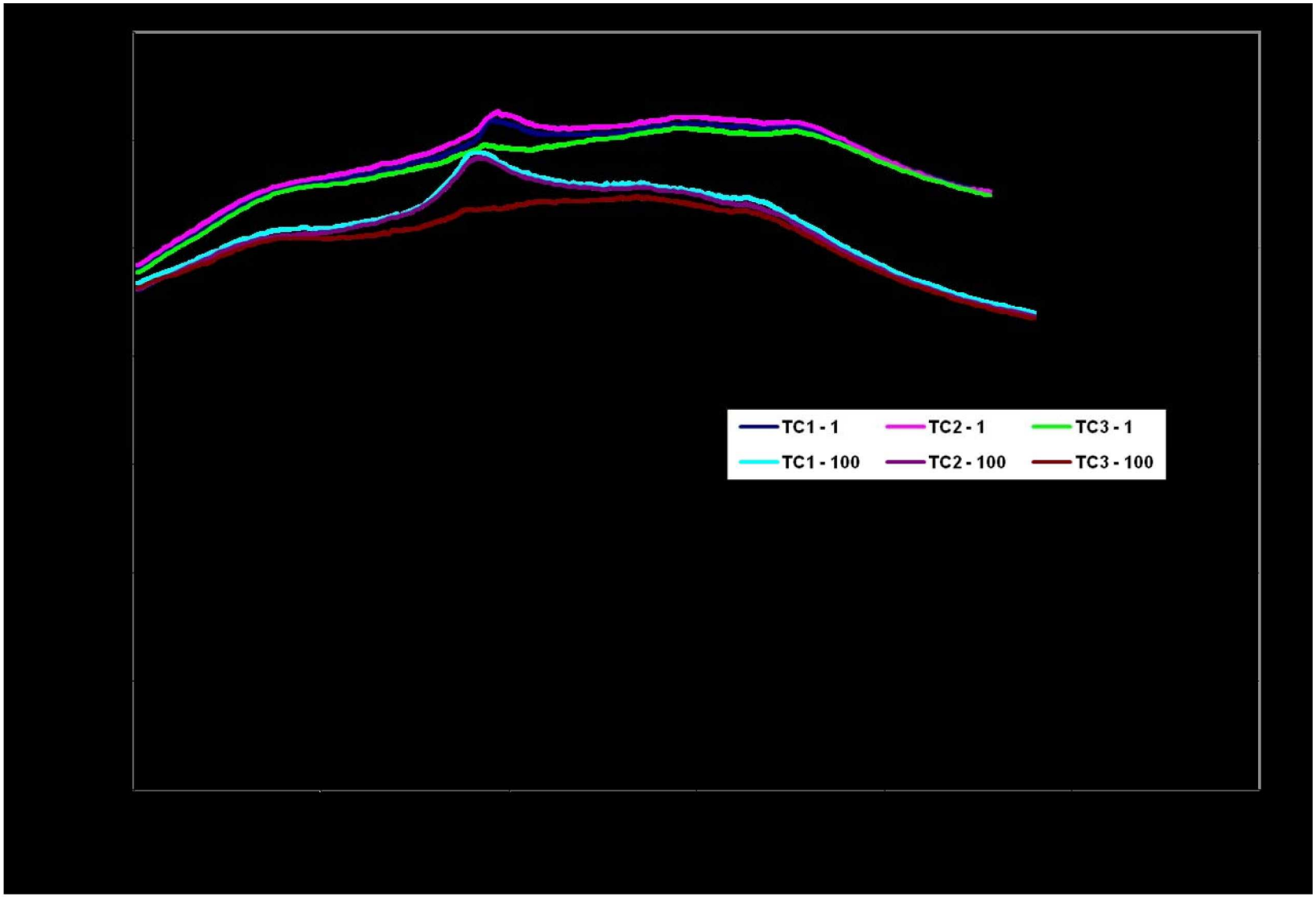
At 2nd Cycle:
Max volt difference: 60 mV
Diff between lower voltage banks is 40 mV

At 100 cycles:
Max volt difference: 70 mV
Diff between lower voltage banks is 40 mV

Cycle Life Test for 5X5 Lithium-ion Matrix Pack (with HAM) With One Cell Disconnected

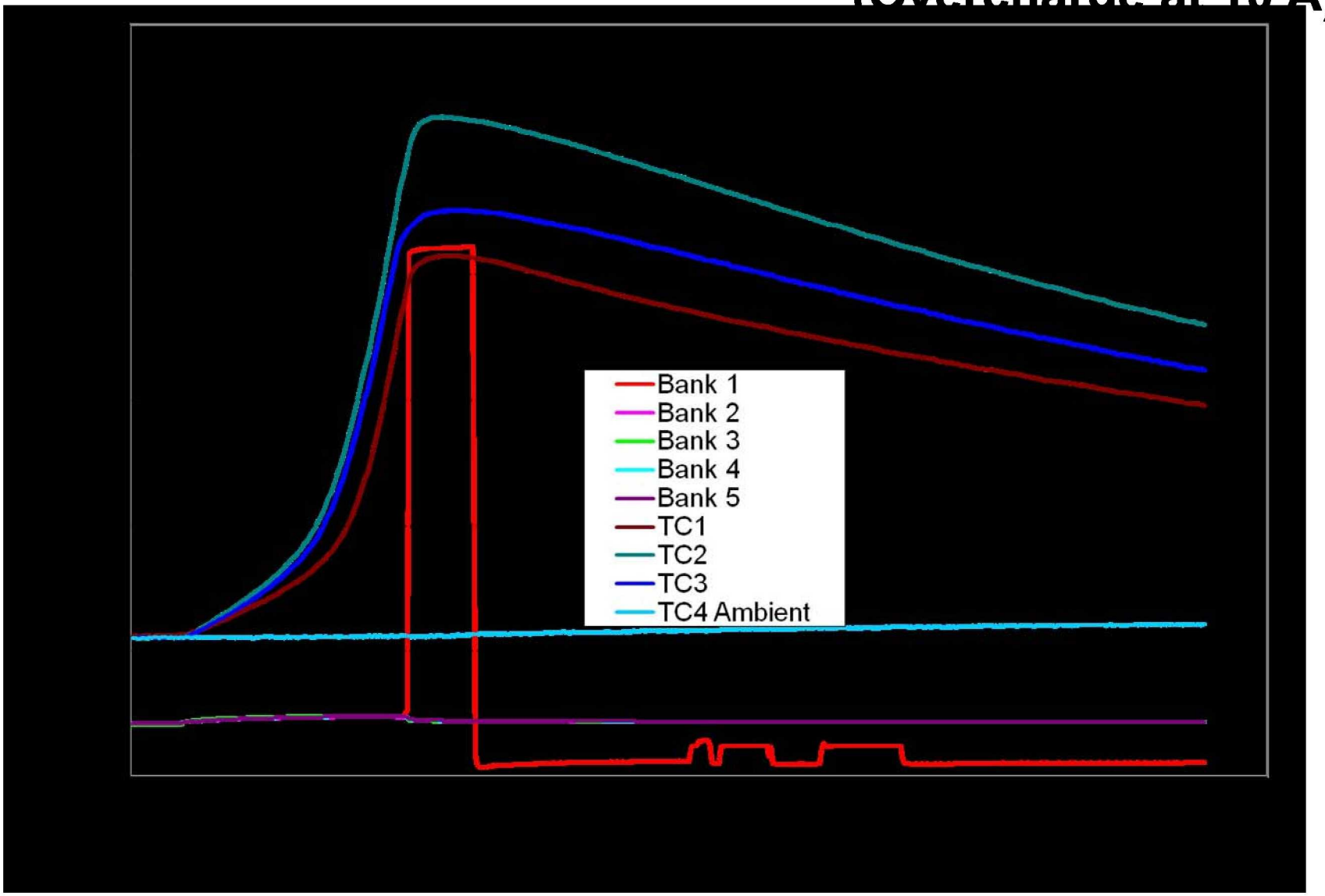


Temperature Profile for 5X5 Lithium-ion Matrix Pack (with HAM) With One Cell Disconnected



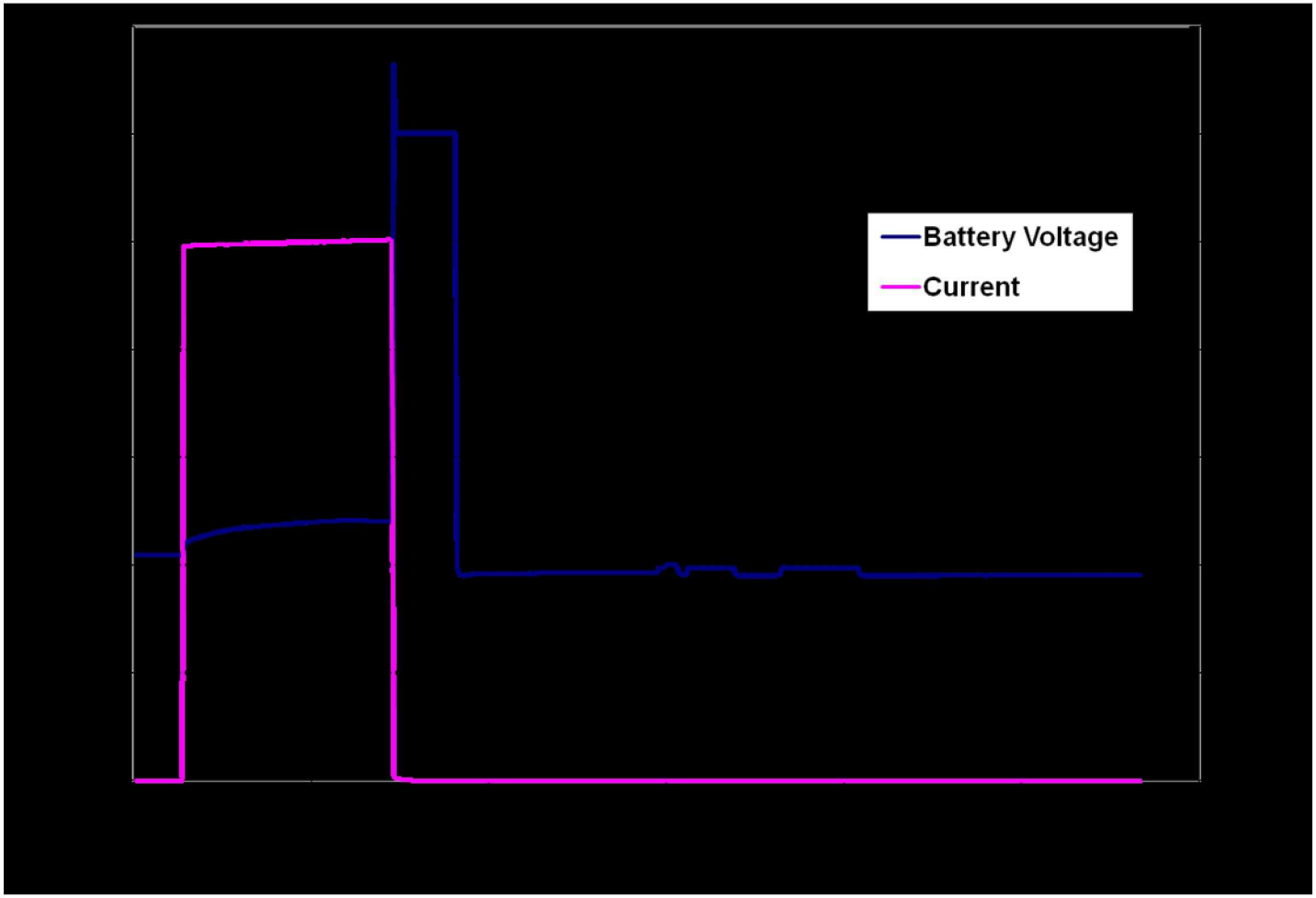
Overcharge Test for 5X5 Matrix Pack (no HAM)

(Overcharge at 10 A)

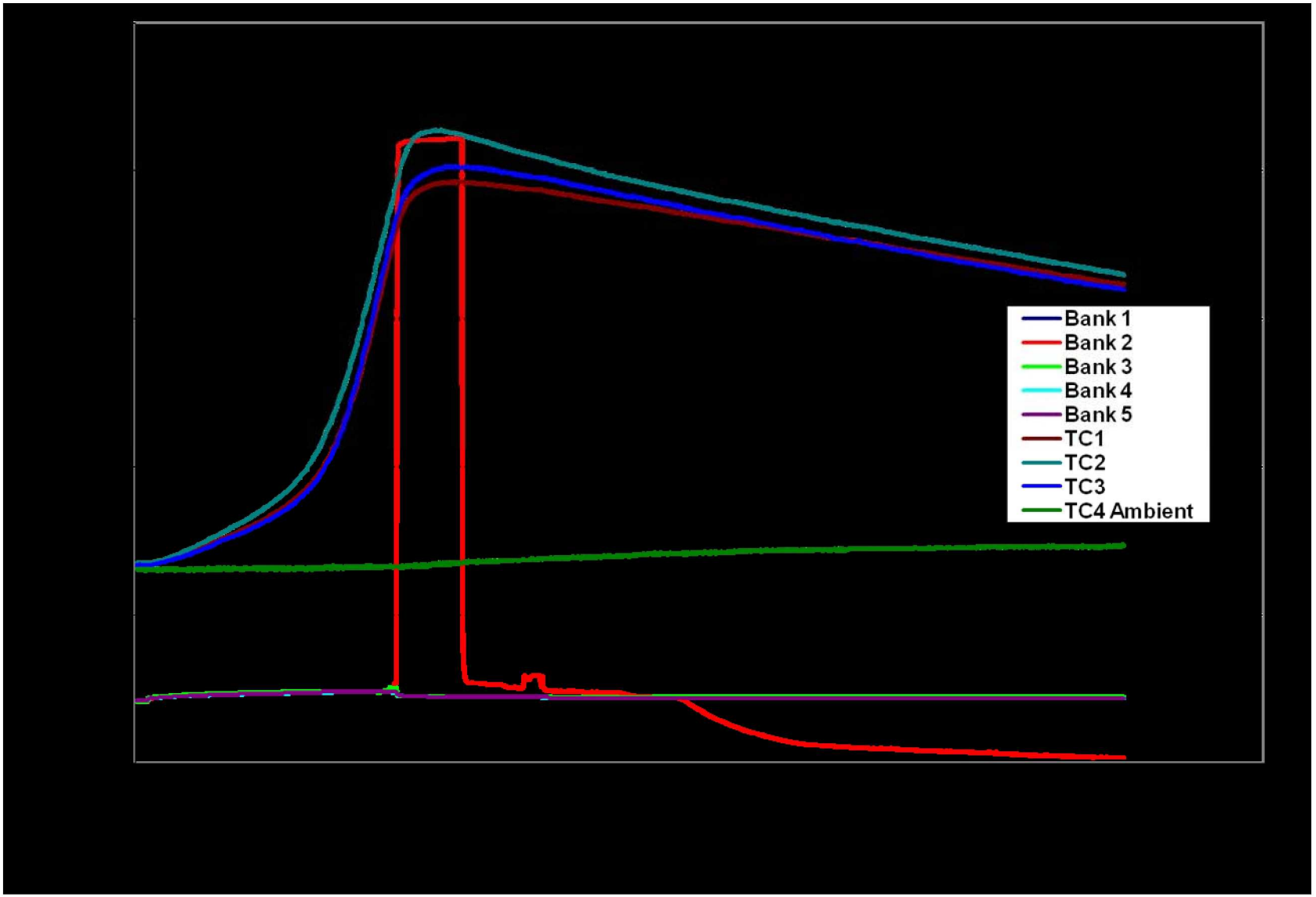


Overcharge Test for 5X5 Matrix Pack (no HAM)

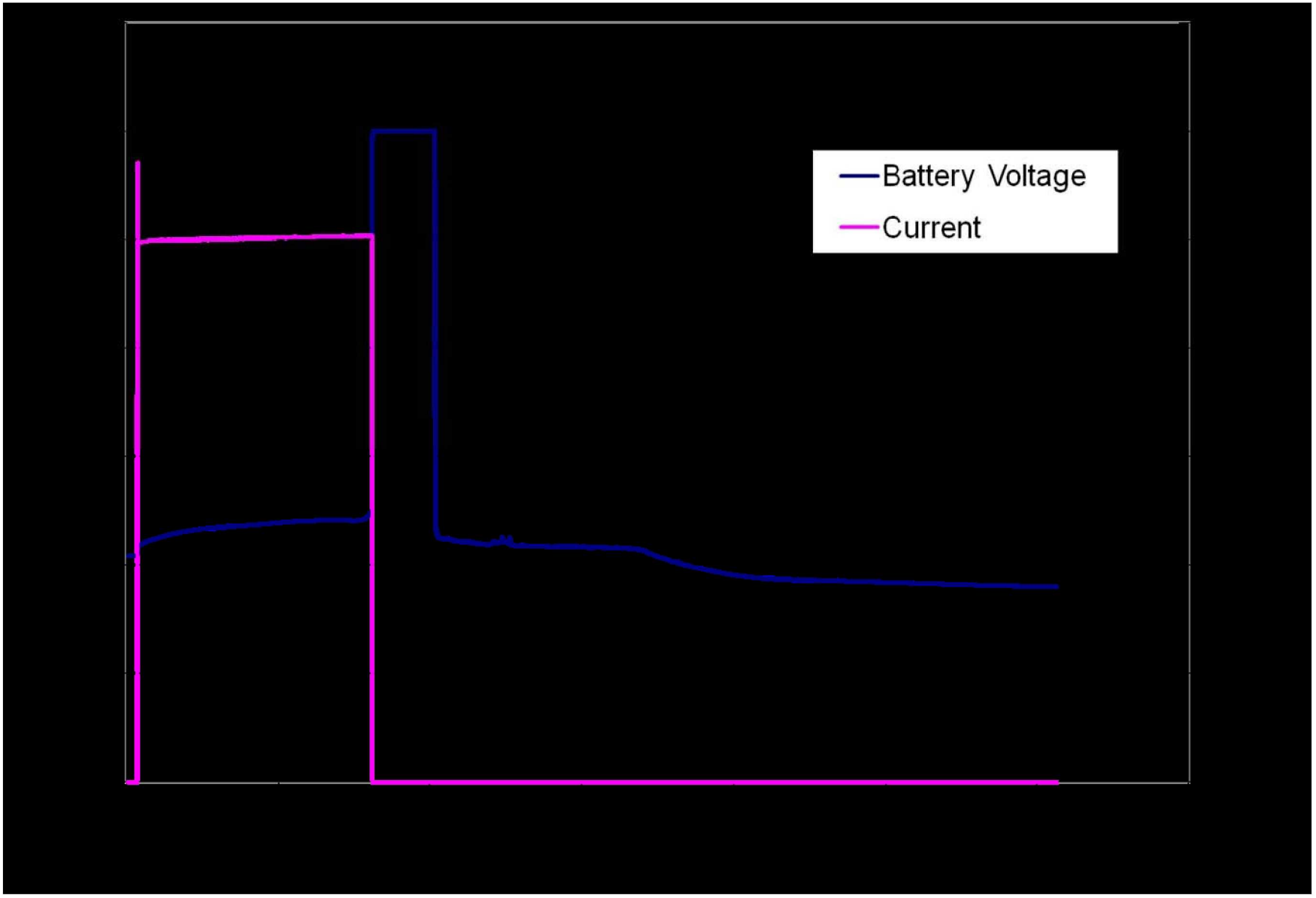
(Overcharge at 10 A)



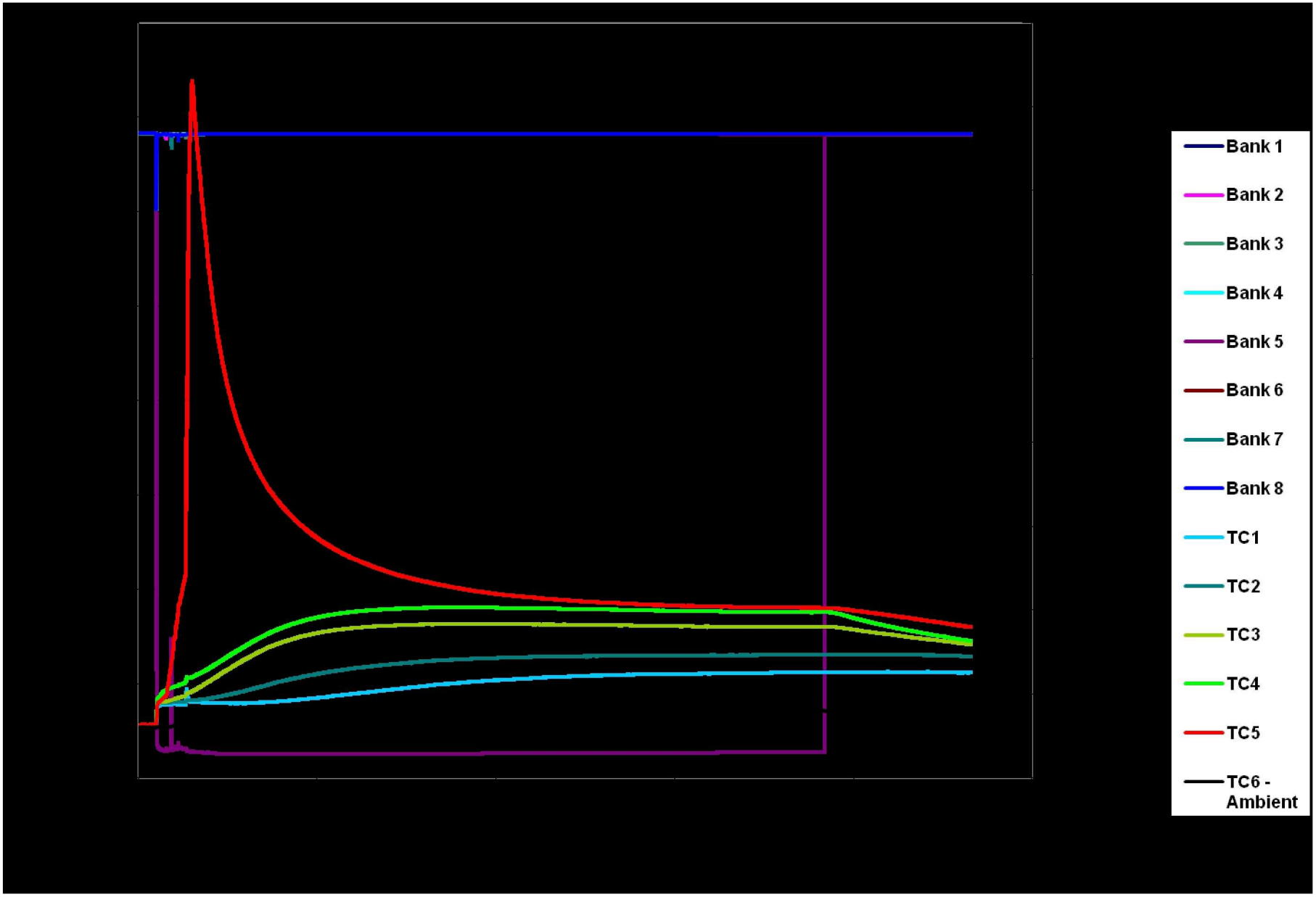
Overcharge Test for 5X5 Matrix Pack (with HAM)



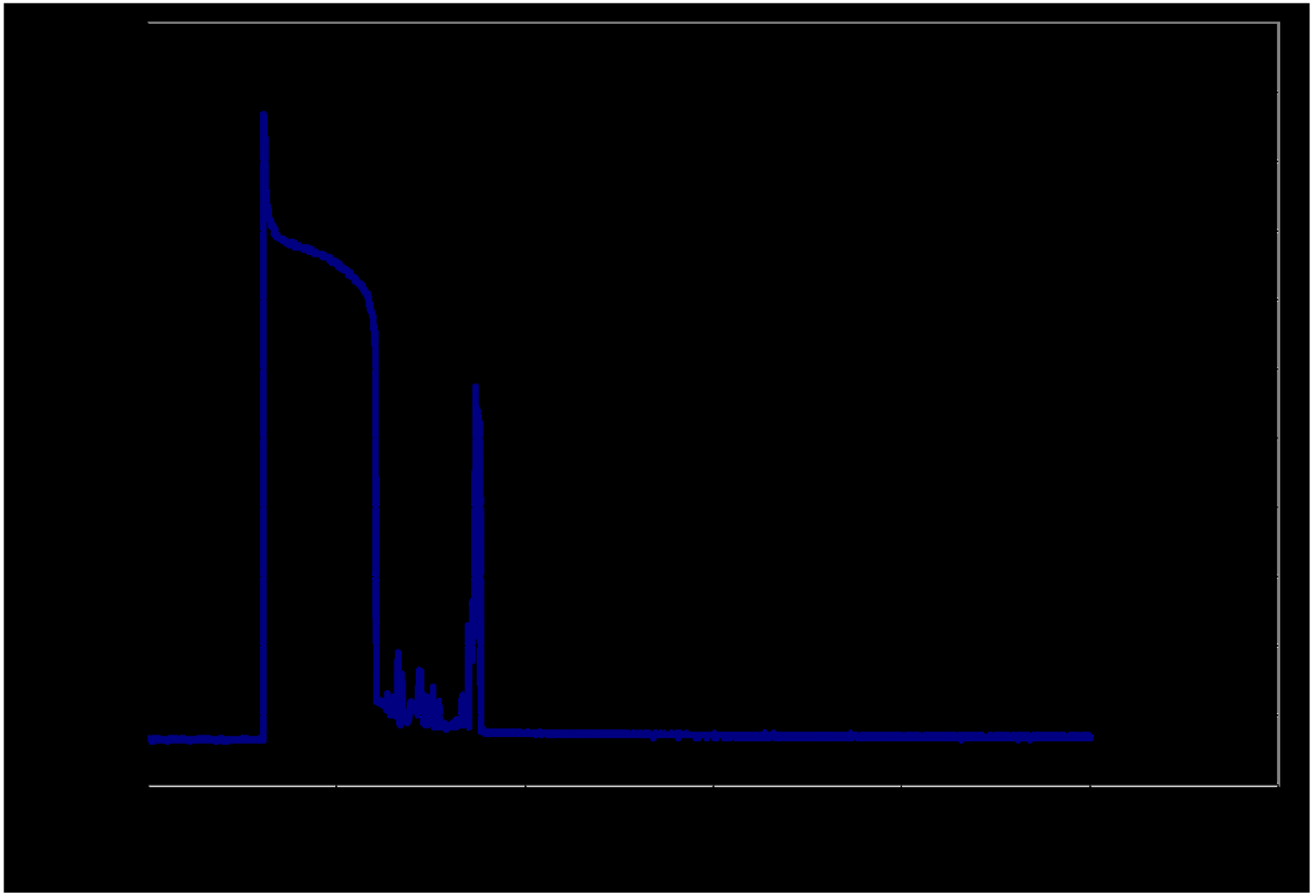
Overcharge Test for 5X5 Matrix Pack (with HAM)



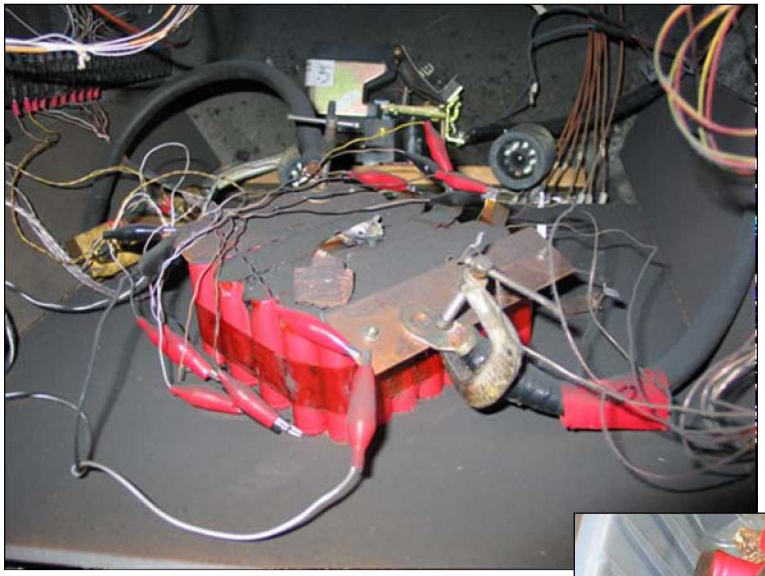
External Short on 8X8 Matrix Pack



External Short on 8X8 Matrix Pack



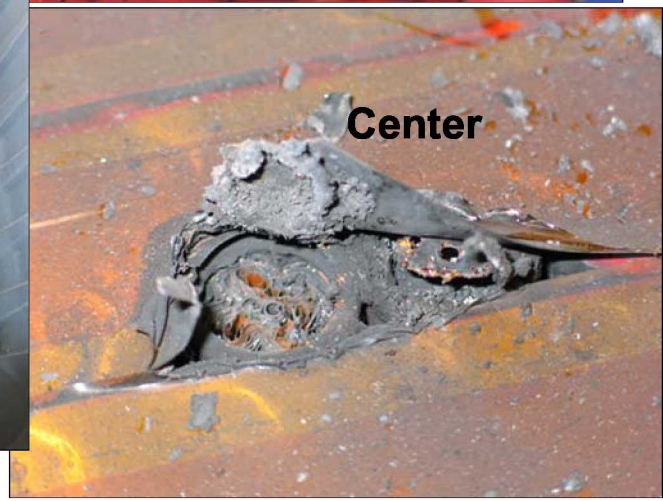
Post- External Short Photo of 8X8 Matrix Pack



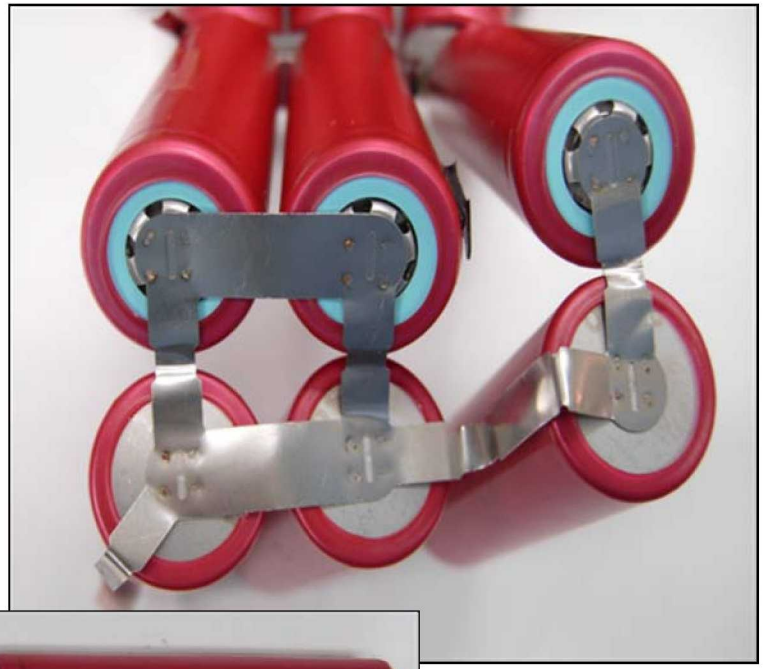
Center Bank

Edge

Center



ISS Lenovo Thinkpad T61P Lithium-ion Battery (Commercial battery pack with Matrix Design Configuration)



Summary and Conclusions

- Matrix Packs display large variations in cell bank voltages at the charge and discharge current (C/2) used in this test program.
- The voltage difference is larger at the end of discharge than at the end of charge under the conditions studied.
- Disconnection of a cell from the pack leads to a larger voltage difference during discharge (greater than 2.0 V) between the bank that has one less cell and the other banks.
  - Thermal profile does not show any significant changes or increase in temperature after one cell was disconnected from the bank in spite of falling to very low voltages at the end of discharge.
- All tests on the matrix pack with the HAM displayed lower max in general due to the placement of thermocouple on the outside of the HAM rather than on the cells.
- Disconnection of cells has almost no influence on the performance of the packs and does not show any abnormal thermal changes for the 100 cycles obtained in this test program. Longer cycle life may influence the performance especially if the low voltage cell goes into reversal.
- Overcharge leads to CID activation of cells. If the matrix configuration has a larger number of cells in series, (more than 5 S configuration), the limitations of protective devices may manifest itself irrespective of it being in a matrix configuration.
- External short circuit causes a fire with expulsion of content from some cells. The fire does not propagate itself laterally, but if there was cell module stacking, then the fire would cause the cells above it to also go into flames/thermal runaway. Limitations of protective devices are observed in this case as the PTCs in the cells did not protect under this abusive condition.
- Matrix configurations seem to provide protection against lateral propagation of fire and flame.
- Matrix pack configuration seems to provide good performance in spite of losing cell connections; at least for the configuration tested under this program.